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THE SIZE DISTRIBUTION OF INDUSTRIAL DUSTS

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THE SIZE DISTRIBUTION OF INDUSTRIAL DUSTS

The question as to the relative significance of various sizes of dust particles in the production of lung fibrosis has as yet not been satisfactorily answered by pathologists engaged on this problem. However, we do know that the inhalation of certain industrial dusts has been found to be associated with definite injury to the pulmonary tissues. Hence a knowledge of the size frequency of these dusts might cast some light on this problem. Of equal importance is the fact that such data will determine to a large degree the type of dust-sampling instrument and the method of dust counting to be employed in evaluating the industrial-dust hazard.

Moir (*1*), Watkins-Pitchford (*2*), and Mavrogordato (*3*), of South Africa, have shown that the majority of the dust particles recovered by them from both human and animal silicotic lungs were between 1 and 3 microns in size. Only 13 percent of the particles were found to be less than 0.5 micron. These results have been recently checked by Scheid (*4*) of Germany. Drinker (*5*), in comparing the size frequency of the particles measured by Moir with the particles found by him in the sputum of men employed in ore mills, found a close correspondence. The results of these findings raise two pertinent questions; namely, (*a*) to what extent are minute particles of dust retained by the human lungs, and (*b*) do appreciable percentages of industrial dusts ever fragment into those minute sizes less than 0.5 micron?

The work of Drinker (*6*) and his associates and that of Brown (*7*) (*8*) on the retention of certain dusts and fumes by man when known amounts were breathed, seem to indicate that the coarser suspensions were retained more effectively than the more finely divided fumes. Percentage retention was found to be directly proportional to particulate size and to the density of dust suspended in the air. Owens (*9*), upon measuring the amount of dust in expired air of London inhabitants, found that only 25 percent of the dust was retained. The average size of the dust inhaled in Owens' experiments was about 0.5 micron. Sayers and his coworkers (*10*) reported that fine particulate matter such as lead dust from automobile exhaust gas was retained to an average extent of only 15 percent of the amount inhaled.

This work on dust retention seems to bear out the theory that dust particles of a size less than 0.5 micron play but a small role in the problem of industrial dust inhalation and in a manner disposes of the first question raised. The answer to the second question—that is, the ability of the ordinary industrial process to fragment appreciable quantities of dust to a size less than 0.5 micron—is best answered by a particle-size study of the dusts actually suspended in industrial atmospheres.

The present contribution deals with such a study of the size frequency of certain industrial dusts encountered in the course of investigating the health of workers in dusty trades. In addition, a discussion is presented concerning the sampling and enumeration of aerial dusts in relation to the results obtained on the size range of such dusts.

INSTRUMENTS AND METHODS USED IN STUDY

The obvious procedure for the sampling of atmospheric dusts for particle-size studies would be to employ the same instrument utilized in sampling dust for quantification. In the past, however, the Owens jet dust counter (*11*) has been employed extensively for such investigations, although of late impinger samples have been utilized for this purpose (*12*). The Owens' samples lend themselves more readily for particle-size measurements than do impinger samples, since the sample in the form obtained is immediately available for microscopic examination, may be readily photographed and moreover collects the dust directly on a cover slip in practically the form it exists in the atmosphere. In order to determine the sizes of particles obtained by the two instruments comparative studies were made on several samples collected with the Owens and impinger. The impinger samples were prepared by placing several drops of the dust suspension in the water on a microscope slide, evaporating the water rapidly on an electric hot plate, and covering the smear of dust with a cover slip. The particles were measured under oil immersion with the filar micrometer method. Table 1 presents the comparative measurements and indicates that a very close relationship exists between the size of dust particles collected by the two instruments. For all practical purposes, therefore, the Owens apparatus may be used in collecting dust samples for particle-size studies, and was so utilized in the present investigation.

TABLE 1.—*Comparison between Impinger and Owens dust measurements*

Size group in microns	Owens		Impinger	
	Number	Percent	Percent	Number
0–0.49	42	6.0	6.0	41
0.5–0.99	387	55.3	53.6	375
1–1.49	193	27.6	29.0	203
1.5–1.99	48	6.9	6.0	42
2–2.49	14	2.0	3.7	26
2.5–2.99	10	1.3	1.3	9
3–3.49	6	.9	.4	4
Total	700	100.0	100.0	700

After obtaining dust samples, the cover slips were mounted in the usual manner. The dust particles were measured by the use of a filar ocular micrometer (*13*) at a magnification of 1,000 diameters (oil immersion objective). The horizontal diameter of at least 200 dust particles in several representative fields was measured for each sample. With this magnification it was found possible to measure particles as small as 0.5 micron in size, while particles smaller than this size are easily distinguished at this magnification and their presence recorded.

Photographic methods have been suggested and used for measuring dust particles; but, in order to obtain good photomicrographs, it is essential that the dust particles be in one plane, free from Brownian movement and well dispersed. Since industrial dusts are seldom of a uniform size, it is difficult to fulfill the first requirement. At the beginning of this study a comparison was made between the results obtained with the direct filar measurements and the photographic method on a typical industrial dust sample. This comparison demonstrated that the simpler and less expensive filar method yielded practically the same results. Since the filar method fulfilled the requirements of our problem, it was selected for the present study.

RESULTS OF STUDY

Table 2 presents the results of the measurements of some 8,000 industrial dust particles and 18,000 outdoor dust particles. The latter measurements were obtained during the course of study of the atmospheric smoke pollution problem in our large cities and are presented for the sake of comparison. The number of samples obtained for each dust, the median size,[1] and the average frequency in percent for each size group is indicated in this table. In all, 34 samples of 13 different kinds of industrial dusts were examined. These dusts ranged from the dust present in sandblasting operations to that associated with the fine pulverizing operations in trap rock and talc milling plants.

[1] The median is the center item in an array and may be strictly defined as a point on the abscissal scale of a frequency distribution with 50 percent of the items on either side.

Table 2.—*Size-frequency distribution of various industrial dusts as compared to outdoor dust*

[Average frequency in percent]

Kind of dust	Number of samples	Median	Size group in microns											
			0-0.49	0.5-0.99	1-1.49	1.5-1.99	2-2.49	2.5-2.99	3-3.49	3.5-3.99	4-4.49	4.5-4.99	5-5.49	5.5-5.99
Outdoor dust	179	0.5	56.0	41.0	2.5	0.5	----	----	----	----	----	----	----	----
Sandblasting	9	1.4	1.4	19.7	34.7	20.3	12.6	5.2	2.8	1.6	1.1	0.2	0.2	0.2
Granite cutting	4	1.4	2.0	19.0	33.6	24.5	10.4	4.6	3.1	.6	.9	.3	1.0	----
Trap-rock milling:														
Crusher house	1	1.4	----	13.0	39.0	33.0	10.5	2.5	2.0	----	----	----	----	----
Screen house	1	1.3	2.0	31.5	33.0	16.0	10.0	4.5	2.5	.5	----	----	----	----
Disk crusher	1	.9	10.0	48.0	31.0	6.0	3.0	1.0	1.0	----	----	----	----	----
Foundry parting compound	2	1.4	.5	22.0	42.0	17.3	9.2	5.0	1.5	2.0	.5	----	----	----
General foundry air	1	1.2	----	26.0	48.0	17.0	8.0	1.0	----	----	----	----	----	----
Talc milling	1	1.5	----	16.0	32.0	20.0	13.0	7.0	5.0	2.0	2.0	2.0	----	1.0
Slate milling	1	1.7	1.0	13.0	29.0	17.0	14.0	14.0	6.0	4.0	1.0	----	1.0	----
Marble cutting	1	1.5	----	12.0	37.0	21.0	10.0	11.0	3.0	----	1.0	2.0	2.0	1.0
Soapstone	2	2.4	1.2	16.0	19.0	13.0	11.0	6.0	6.5	4.5	5.5	3.3	2.5	11.5
Aluminum dust	1	2.2	3.0	8.0	20.5	14.0	11.5	9.0	6.5	3.0	3.5	4.0	7.0	10.0
Bronze dust	1	1.5	1.0	12.0	33.5	25.0	21.0	6.0	1.5	----	----	----	----	----
Anthracite-coal mining:														
Breaker air	2	1.0	7.0	51.0	26.0	8.0	3.0	3.0	2.0	----	----	----	----	----
Mine air	1	.9	11.0	60.0	17.0	7.0	3.0	1.0	1.0	----	----	----	----	----
Coal drilling	1	1.0	1.0	55.0	34.5	7.5	1.5	----	.5	----	----	----	----	----
Coal loading	3	.8	11.5	56.3	24.3	5.5	1.5	.7	.2	----	----	----	----	----
Rock drilling	1	1.0	4.0	49.0	25.5	12.5	5.5	1.5	.5	1.5	----	----	----	----

An examination of the data in table 2 discloses a striking difference between the size frequency of outdoor dust and indoor industrial dust. Ninety-seven percent of the outdoor dust particles were found to be of a size less than 1 micron in diameter, with a median size of 0.5 micron. Practically no dust particles larger than 1.5 microns were found to exist in outdoor air. These results on the size frequency of outdoor dust are similar to those obtained by Owens in London (*9*). In contrast with this result we find that only 4 percent of the industrial dust particles are less than 0.5 micron, and but 32 percent less than 1 micron. The average (median) size of these particles was found to be 1.4 microns. It is evident from the results shown in table 2 that the majority (60 percent) of the dust particles present in industrial atmospheres investigated by the writer was found to be between 1 and 3 microns in average diameter, with but 7 percent of the particles exceeding 3 microns.

One of the interesting findings of the present study is revealed by the distribution shown in table 2, which indicates that although no two industrial dusts have the same size frequency, differing for the same dust created by different operations, yet for all practical purposes the dust particles fall into very narrow limits, the majority of them being between 1 and 3 microns. From this evidence on the particle-size distribution of industrial dusts in air it is apparent that our concern should be only for those particles ranging from 0.5 micron to 5 microns, and that the lower limit of particle size may certainly be taken at 0.5 micron.

An application of the size-frequency data presented in table 2 to some of the results obtained in studies of dust concentrations in industry reveals very interesting information. Figure 1 presents a comparison between the number of dust particles of different sizes found in the general air of granite-cutting plants and that found in outdoor air in the vicinity of these plants. The average dust counts for both the granite-cutting plants (20.2) and the outdoor air (4.7 millions of particles per cubic foot) are based on about 50 samples obtained with the impinger apparatus. It is obvious that if we apply the size-frequency data shown in table 2 (computed with a class interval of 0.1 micron) to the average dust counts just cited, that in the case of the indoor samples we cannot expect to obtain appreciable counts until the 0.7 micron size and larger sizes are reached, whereas apparently the opposite would hold true for the outdoor dust samples. This result is what one would expect from a consideration of the particle-size data of the two types of dusts and is merely presented to illustrate more lucidly the significance of the data. These results serve to indicate very clearly that if we are to differentiate between dusts present in normal air (not proved to be harmful) and certain dusts found in industrial air (known to be hazardous), we should

leave out of consideration those particles that are less than 0.5 micron in diameter. (The two curves actually cross at 0.6 micron.)

THE SAMPLING AND ANALYSIS OF INDUSTRIAL DUSTS

From the data presented in this paper it is apparent that in order to obtain a representative sample of industrial dust in air, one should employ an instrument capable of arresting with a high degree of

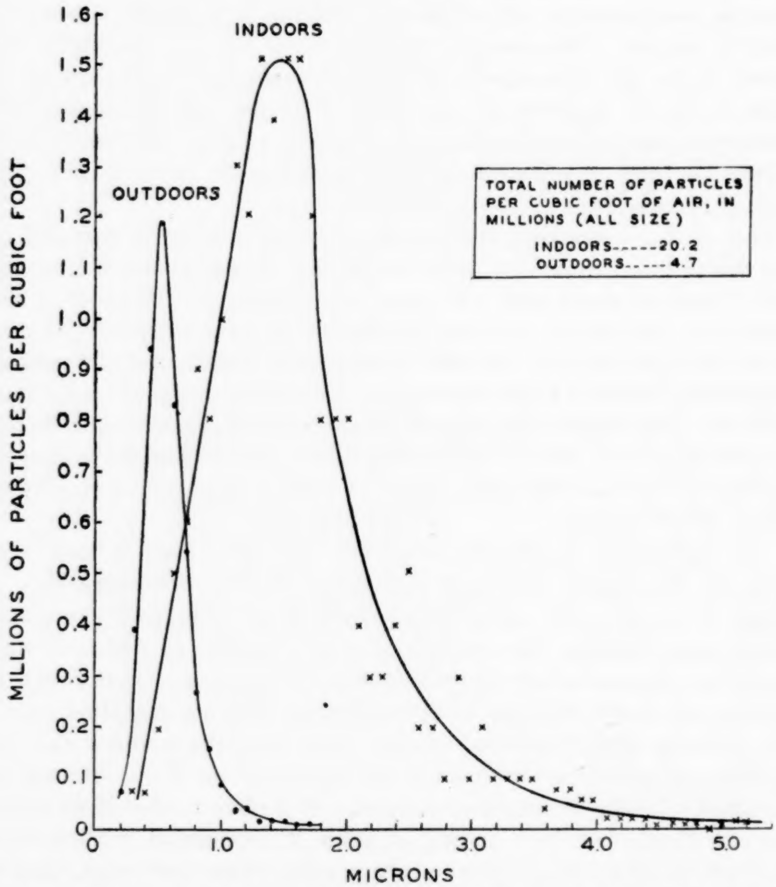

FIGURE 1.—Amount of dust of different sizes found in the general atmosphere of granite cutting plants, in comparison with that outdoors in the vicinity of these plants.

efficiency all kinds of dust, of sizes ranging from 0.5 micron to 5 microns and at both low and high concentrations. In addition, the method of counting the dust in the samples should have small analytical errors and should reveal only those significant particles present in industrial atmospheres. It should not be the aim to count all the dust particles which may be present in the samples (as may be accomplished by either the use of high magnifications, dark-field illumina-

tion, or combinations of both), since it is necessary to differentiate between the dust content in normal air and industrial air. As has already been shown in this paper, this difference is sharply marked insofar as the dust particles between 0.5 micron and 5 microns are concerned; but this difference would be masked and lost should we include in our determination the particles of ultramicroscopic size which are present in vast numbers in all air.

Many methods have been devised and used for the purpose of determining the quantity of dust in air. Suffice it to say that for the purpose of dust sampling in either high or low concentrations, the Greenburg-Smith impinger apparatus (*12*) now finds universal favor. This instrument has been used by the United States Public Health Service in all of its dust studies for the past 12 years and is also being used by other workers in this country and abroad. Since this instrument has already been described in numerous publications, no further mention will be made at this time concerning construction details or method of operation. However, certain advantages that this instrument possesses over other dust-sampling instruments should be mentioned. These are, briefly, a high dust-collecting efficiency at both low and high concentrations (98 percent against finely-divided silica dust), simplicity of construction, low cost, and finally it permits samples to be examined either microscopically, gravimetrically, or chemically. Recently, Hatch (*14*), in studying the operating characteristics of the modified impinger developed by him, investigated the effect of particle-size on the sampling efficiency of this instrument. Against a silica-dust suspension of approximately 1.5 microns average diameter, this instrument yielded an efficiency of more than 98 percent at the normal sampling rate of 1 cubic foot per minute. Even against very finely-divided magnesium oxide fumes, formed by burning magnesium ribbon in the flame of a blast lamp, this instrument showed an efficiency of 55 percent.

The method of dust counting employed by us during the past 12 years has been presented in detail elsewhere (*12*) (*15*). Recently, in order to establish the lower limit of particle size revealed by our standard microscopic technique, quartz dust particles ranging from 0.4 micron to 1.6 microns and averaging 0.9 micron were examined by this technique. This study showed that with our method of counting dust an experienced observer is capable of seeing quartz dust particles as small as 0.7 micron. Our size-frequency data shows that only 15 percent of the dust in industrial air is less than 0.7 micron. It is obvious, therefore, that our present method of counting dust is capable of disclosing about 85 percent of the dust particles collected by our instrument. The small percentage of dust our method fails to reveal is negligible, when one takes into consideration the sim-

plicity of the method, the fact that results may be checked by trained observers, and that it is one of practical application.

The best criterion of the value of any method of measurement is its successful use in a practical application. Such a test was offered in the study of the health of workers exposed to the inhalation of granite dust (*16*). In this study it was definitely established that a high correlation existed between the intensity of exposure to dust and the degree of silicosis and active tuberculosis. Similar good correlations were also found in a more recent investigation made in the anthracite coal-mining industry (*17*). It is obvious, therefore, that the technique of dust analysis which we have been using constitutes a valuable index of the hazardousness of dust inhalation.

SUMMARY

The results of measurements of 18,000 outdoor dust particles showed that nearly all of these are less than 1 micron in average diameter. The median size was found to be 0.5 micron. In contrast with this result it was found that only 32 percent of about 8,000 industrial dust particles were less than 1 micron in size, the majority (60 percent) being between 1 and 3 microns. The median size of the industrial dust particles was found to be 1.4 microns. These results clearly indicate that in conducting industrial dust studies our concern should be only for those particles ranging in size from 0.5 micron to 5 microns.

The instrument used in sampling industrial dust in air, the standard impinger apparatus, is shown to be capable of collecting, with a high degree of efficiency, dust particles of the sizes found in this study. The standard method used in enumerating dust particles is shown to take into account about 85 percent of the dust present in industrial atmospheres. In addition, our studies have shown that a high correlation exists between dust counts obtained with our technique and the degree of silicosis and tuberculosis found in a study of the health of workers exposed to certain siliceous dusts. The present study clearly indicates that the method used in enumerating dust particles collected by the impinger apparatus constitutes a valuable and practical index of the hazardousness of dust inhalation.

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